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The Winter Gardens, Sheffield, UK

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Summary

This paper details the design and construction of the Winter Gardens, the landmark building for the city centre regeneration of Sheffield, UK. The 75m long Glulam frame is formed with a series of arches up to 22m high housing a collection of temperate plants and trees. The building was opened by the Queen and Duke of Edinburgh on 22 May 2003.

Keywords: Glulam; Arch; Timber; Larch; Greenhouse; Radial Tensile Stress; Reinforcement; Sustainability

1. Background

Sheffield is a city with a proud and prestigious industrial heritage synonymous with metal working and in particular, precision engineering of high quality steel. However, in common with much of Western Europe, the city centre foundries have closed down. The 'Heart of the City' project, supported by the Millennium Fund together with national and regional government, was launched to regenerate and revitalise the city centre. The Winter Gardens and the adjacent sister project, the Millennium Galleries, are the catalyst for the regeneration. They provide the city with a new focus and identity embodying the spirit of a proud city. Importantly, both buildings are free to the public.

2. Concept

2.1 Context

The Winter Gardens were conceived as a covered galleria, linking the arts and academic quarters with the civic and commercial quarters. The development of the form was to be influenced by the presence of the building on the skyline and the notion of place in a city of grand monumental buildings. The regeneration scheme envisaged the building with exotic evergreen planting as a winter alternative to the adjacent Peace Gardens with their foundations and lawns

These criteria required a delicate enclosure sensitive to the planting, filtering light and air, providing shade and ventilation whilst the urban context required architecture on a grand noble scale.

2.2 Form and Material

The planting required a tall large volume space clear of structural support on a long narrow site. A natural form and material was sought that responded to, and advertised, the internal function. The catenary arch fulfilled these objectives. The arch is a pure natural form, its aesthetic conveys a sense of strength, holding its own against the surrounding grand civic buildings. The profile steps from 11m high arches at the entrances to the tallest 22m high arches at the centre, this presents human scale entrances to embrace visitors.

Timber was selected not just for visual appearance. It was a conscious effort on the part of the project team that the plants provide an important reminder of their economic, ecological, medicinal and educational value to mankind. They underline the importance of a careful and balanced use of our planets precious resources. To be consistent with this message timber was a natural choice.

As well as the rational design reasons for using timber, timber represented a fresh forward looking material for what is known as “the steel city”. Steel would have been a retrospective, nostalgic material for what was to be a new ‘Heart of the City’. Similarly, concrete has negative associations with inhuman architecture and social upheaval of mid 20th century industrial decline. In this context the team and the client strongly believed it was time for a new material, it was time for timber.

3. Structure

3.1 Superstructure

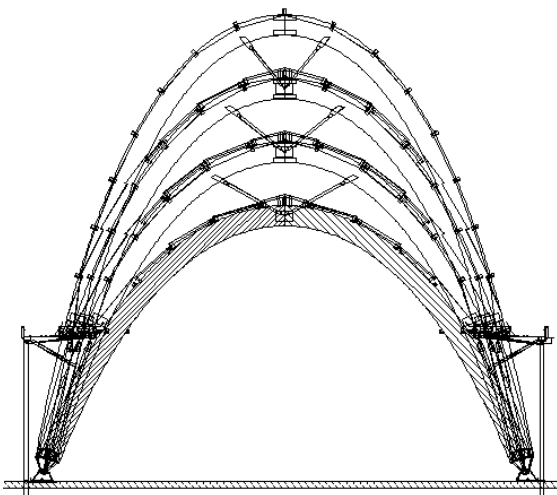


Figure 1 – Cross Section

Alternate arches stop at gutter level to allow access along the side elevations. The axial loads are supported by the raking struts, whilst the horizontal thrust, due to the vertical loads as well as direct lateral wind loads, is transferred through the gutter to the arches that continue to the ground.

The gutter is formed from galvanised steel plate, as well as transferring the forces noted above, it also provides a maintenance walkway and service route. The width of the gutter is determined by the gap between the arch and the building boundary.

The catenary arches give a very simple and efficient structural scheme. A catenary, the profile formed by a hanging chain, results in pure axial forces under gravity loads and a large volume space. The arches are designed as continuous with pinned bases tied at by the ground floor slab. The bases are a constant 10.7m apart.

This solution resulted in simple pinned connections and a great reduction in the mass of the structure compared with portal frames or trusses. The cost, aesthetic and constructional benefits were significant.

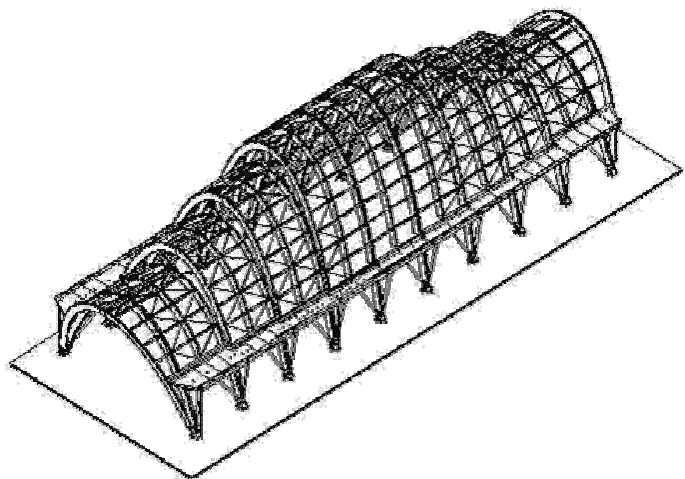


Figure 2 - Isometric View

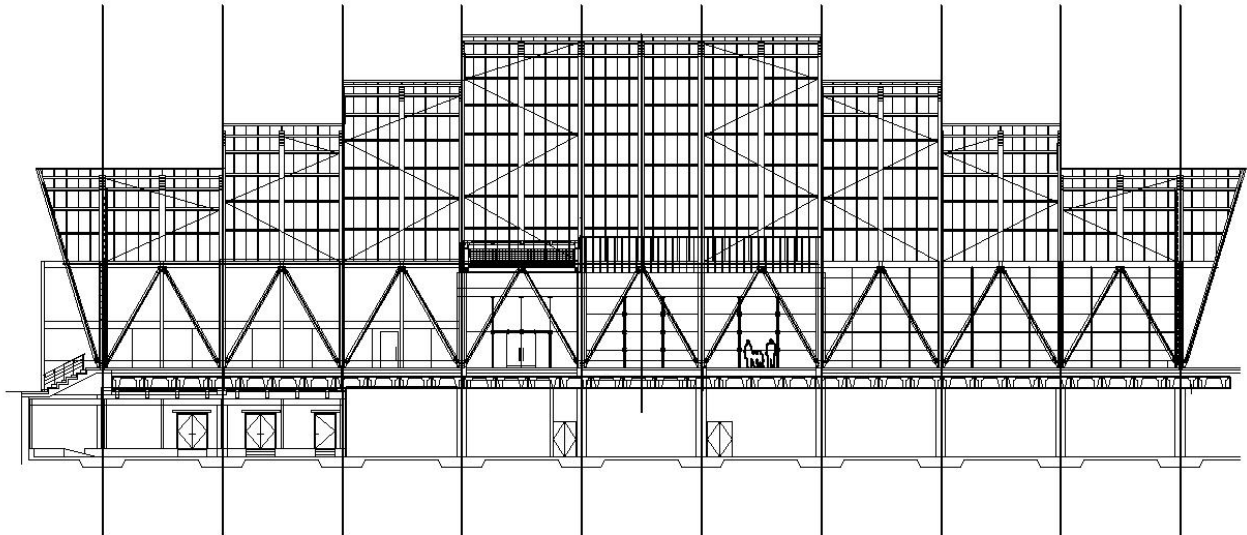


Figure 3 – Long Section

Each roof level is designed as an independent structural module, 7.5m wide giving an overall length of 67.5m. The steps are formed by two arches of each height placed side by side with a gap of 30 mm. Other than the gutter, there is no connection between each height module.



Figure 4 – Base Detail

The principal structural element sizes are:

- Arches - 210mm wide x 910mm deep
- Purlins - 150mm wide x 225mm deep
- Raking Struts – 245 mm diameter

All timber is Polish Larch to grade GL28, and fabricated in Germany by Merk. The steelwork is mild steel, galvanised to avoid staining the wood.

The initial design used BS5268 [1] whilst connection and detailed design used EC5 [2]. This highlighted a difference in the codes for radial tensile forces perpendicular to the laminations in curved elements.

Comparing the two codes at the apex of the largest arch:

BS5268 Clause 3.5.3.3

$$\sigma_{t, a, \perp} = 0.25 \text{ N/mm}^2$$

$$\sigma_{t, adm, \perp} = 0.30 \text{ N/mm}^2$$

$$\text{Hence utilisation} = 0.83$$

EC5 Clause 5.2.4k

$$\sigma_{t, 90, d} = 0.22 \text{ N/mm}^2$$

$$f_{t, 90, d} = 0.31 \text{ N/mm}^2$$

$$k_{dis} = 1.4$$

$$(0.01/V)^{0.2} = 0.375$$

$$\text{Hence utilisation} = 1.38$$

The above comparison demonstrates the applied and basic permissible stresses are very similar in the two codes. The difference is that EC5 includes a volumetric factor. The authors have outlined this discrepancy to the committee responsible for BS5628.

The checks to EC5 demonstrated that the apex of tallest arches required reinforcement with dowels perpendicular to the grain. This was designed to the method outlined in STEP lecture E5 [3].

3.2 Substructure

The building is built on a concrete podium providing basement parking and delivery access to the adjacent Millennium Galleries, hotels and offices. The foundations are simple pads cast directly on the shallow siltstone rock strata.

3.3 Glazing

The roof is clad in approximately 1,400 glass panels. These panels are articulated to accommodate the flexure of the arches under wind loading in a similar manner to the plating of an armadillo. Each panel is supported at the top by a hinged fixing attached to the purlins. The bottom edge is supported by a sliding joint that only resists wind load perpendicular to the panel.

The spacing of the purlins and consequent panel sizes was dictated by several factors:

- Maximising standardisation of panel size
- Span limits for the glass and framing system
- Accommodating the variation of radius and length of each arch

The result is that 80% of the glass panels are of an identical size and all panels use the same framing system, fixings and glass thickness. A total of 272 panels are automatically opening as noted below.

The side walls are formed by structural glazing spanning from the ground slab to the gutter. The glazing has a fire drenching system at the interface with the Millennium Galleries that results in 30 minute fire resistance for the glass. A temporary hoarding has been used on the north elevation to be replaced with a glass façade as part of the adjacent hotel currently under construction.

Structural glazing incorporating banks of horizontal louvres has been used for the gable facades. This glazing is supported on a steel sub frame.

3.4 Erection

All components of the superstructure and majority of the concrete ground floor were fabricated off site. The simple repetitive forms provide elegance and economy of effort. The arches were brought to site in two pieces. Two cranes were used to lift the two halves. The bottom of the arches were located in the steel shoes and slowly lowered allowing the arches to meet at the apex, the fit was perfect. A solitary worker in a cherry picker hammered in the dowels to complete the apex flitch plated connection. A superintendent stood by to assist if required.

Meanwhile, two further workers on cherry pickers scuttled about fixing the smaller elements such as purlins and cross wire bracing. This picture shows the simplicity and elegance of the pinned connections and transfer structure. In all, 4 workers and 2 crane drivers erected the entire timber frame in just 8 weeks, an impressive display of the benefits of prefabrication.



Figure 5 – Fixing Purlins

4. Building Environment

4.1 Internal Climate

In horticultural terms the building is a cool temperate house suitable for plants from the Mediterranean and similar climate zones in the southern hemisphere. Frost protection is provided

by underfloor heating utilising a district heat system.

Vents in the roof and at either end of the building open up (in 4 steps) to provide ventilation and induce transpiration cooling from the plants. Throughout the year, high level fans induce air movement dissipating any local climatic extremes.

4.2 Services Integration

A high level services distribution route is located along the gutter. There are 6 galvanised pipes on each side of the building between the gutter and the ground floor slab. Four of these are rainwater pipes and two give segregated routes for water and electricity from the gutter to the basement plant rooms. Being metal, the normal rainwater pipes also form the earth path for the lighting conductors.

5. Why Timber?

5.1 Engineering & Architectural Benefits

Selecting the material and form are very much part of the same dialogue – every material performs well under certain circumstances – change the circumstances and you change the appropriate material.

Long life buildings such as this favour the use of materials that are inherently durable and require minimal maintenance as these costs can be significant over a long period of time. The planting precluded the use of paints, preservatives or solvents in the maintenance of the building. Otherwise the plants would need to be removed on a regular basis as at Kew Gardens, London.

A secondary benefit was a reduced construction cost and programme as there were no finishes to complete, no paints to apply or internal cladding to fix.

Untreated durable timber fulfils these requirements more readily than steel or concrete.

Architecturally, timber has an inherently pleasing aesthetic. Crucially, this aesthetic matures and lasts without dating, independent of the whims of fashion.

5.2 Sustainability

A research study [4] funded jointly by Buro Happold and the UK Department of Trade & Industry examined the sustainability of the project, including embodied and operating energy. This study compared the timber frame with concrete and steel alternatives using the UK's Building Research Establishment rating system, ENVEST.

The environmental impact of constructing the building in timber was compared with that of concrete and steel. This showed the timber as a material had an eco-rating of less than 5% of that for steel or concrete alternatives – a 95% reduction in energy used in the construction.

In addition to this advantage, the weight of the Glulam frame is 65% of the weight of the steel alternative and 15% of the concrete scheme. This represented a cost saving and reduction in environmental impact including less material needed in the foundations.

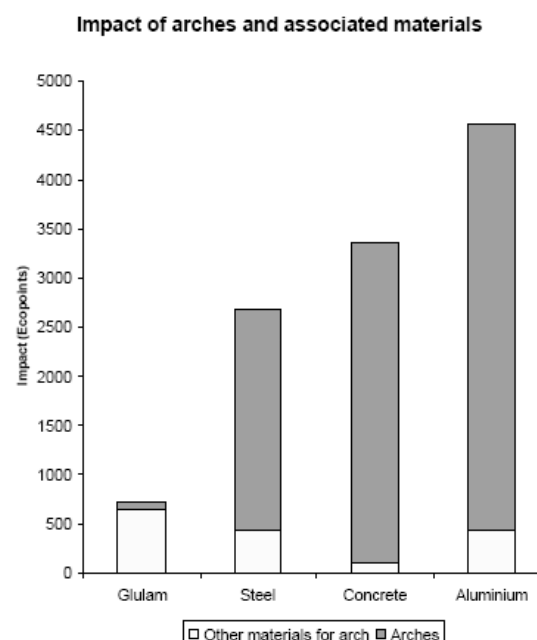


Figure 6 - Environmental impact of arches

6. Conclusion



As a building the Winter Garden is a spectacular building in the heart of the city centre. It is an open transparent public space, for use by the public, both a route and a destination.

The use of timber played a major part in the success of the building on a number of levels –

- Visually the material presents a welcoming and attractive space and place.
- Timber is used from a palette of timber, stone, steel and glass
- It is an appropriate material used in harmony with the function of the space.
- Its sustainability credentials are second to none.
- Very low maintenance for a building intolerant of paints and other chemicals

As a structure it is clear and legible, the forms and materials natural and familiar. The scale is spectacular and awesome. Most importantly as a public building, it provides a memorable experience for all visitors – young and old.

Figure 7 - Completed Building

6.1 Acknowledgements

Client:	Sheffield City Council
Architect:	Pringle Richards Sharratt
Structural Engineer:	Buro Happold
Services Engineer:	Buro Happold
Main Contractor:	Interserve Special Projects
Glazing:	Haran Glass (Roof) & Glastec (Gable walls)
Timber:	Merk

6.2 References

- [1] *BS5268-2:2002 Part 2: Structural use of timber - Code of practice for permissible stress design, materials and workmanship*, BSI, London, 2002
- [2] *DD ENV 1995-1-1:1994: Eurocode 5 Part 1-1 Design of timber structures*, BSI, London 1994
- [3] *STEP – Structural Timber Educational Programme Volume 2*, Centrum Hout, The Netherlands, 1995
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